Extremely Durable and Low-Cost Concrete: Ultralow Binder Content and Ultrahigh Tensile Ductility

PI: Yu Qiao, UC San Diego

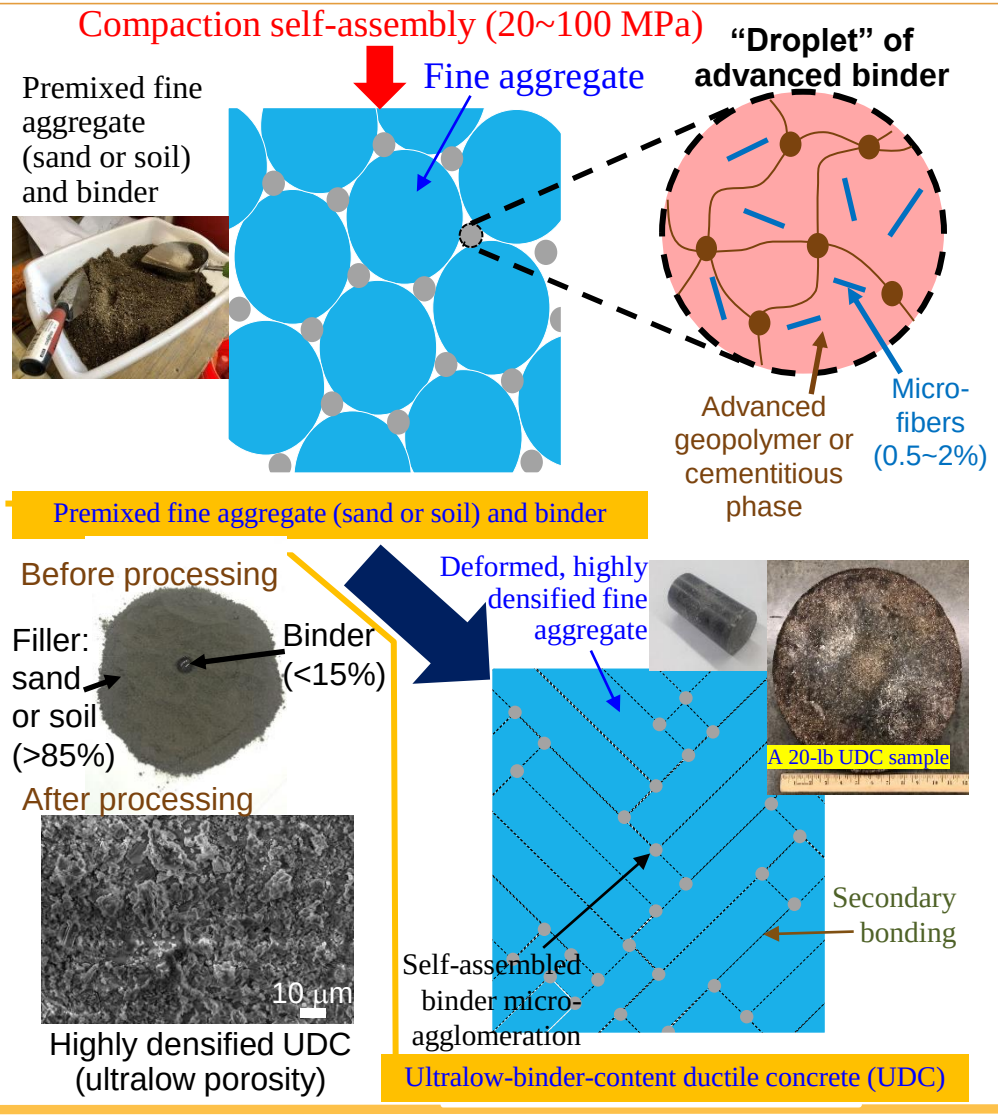
Co-PI: Mo Li, UC Irvine

Project Vision

- Using advanced binder to drastically improve the concrete durability
- Using compaction to simplify mixing and to largely reduce the binder content (much reduced cost, enhanced strength and ductility, reduced carbon emission, etc.)

Total Project Cost:	$1.3M
Length	30 mo.

The Concept



- 0.5~2% microfibers drastically improve the concrete durability
- Compaction (15~20 MPa) to
  - ➢ Simplify the premixing process
  - ➢ Greatly reduces the binder content to only ~15% (reduced cost & carbon emission)
  - ➢ Further improve the ductility and strength

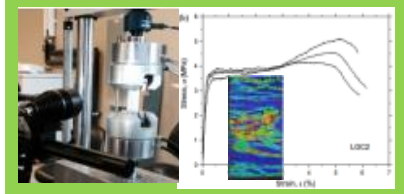
The Team

Research & Development

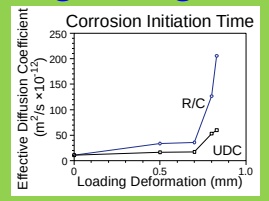
Prototyping & Commercialization

Co-PI Li, Associate Professor at UCI: expertise in chemistry and micro-mechanics of cementitious materials and geopolymers

Binder chemistry and strength design



UDC tailoring for tensile ductility



Durability Validation

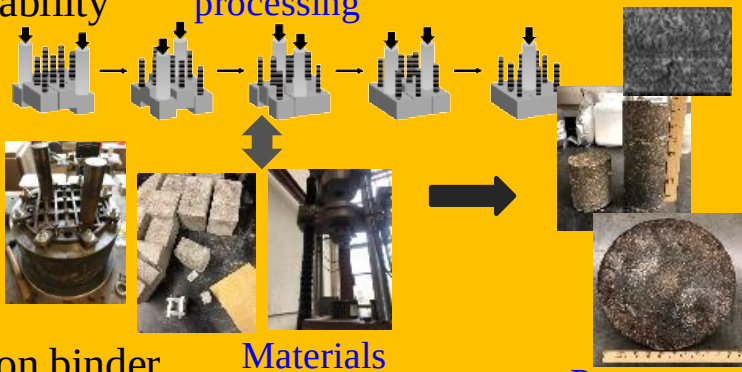
Advanced binder development

Binder strength, ductility, permeability

Requirements on binder viscosity, tackiness, etc.

PI Qiao, Professor at UCSD: inventor of CSA; expert of processing of infrastructural materials

Optimization of processing



Materials characterization

Prototypes

UDC Production

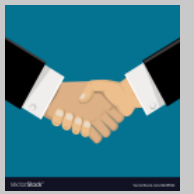
Yeshaya Koblick

TEA

MKT/industry knowledge

IP

T2M plan



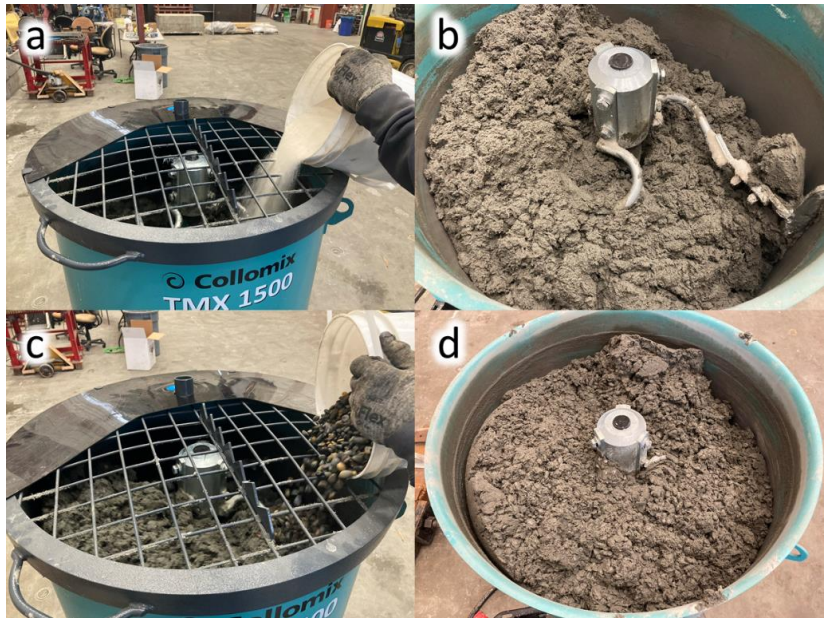
Commercialization

Project Objectives

- Q4: Proof of concept: compaction formation (UCSD)
  - Low binder content (10~15%, compared to ~25% in regular concrete)
  - Adequate strength (>5,000 psi)
- Q4: Advanced binders (UCI)
  - Ductility at least 10X to 100X
- Q8: Production of 500-lb prototypes (UCSD)
- Q10: Characterization of microstructure, mechanical properties & durability (UCI)

- T2M
  - Market niche: precast parts (1/7 of the total construction materials market)
  - Licensing vs. start up

Results (I)



Use a regular mixer to premix

- ~15% portland cement (compared to ~25% in typical concrete)
- ~0.5% microfibers (compared to ~2% in typical UHPC)
- water, sand, gravels, etc.

The premixed material was compacted in a steel mold, up to 15 MPa (~2200 psi)

- The compressive force is applied by portable hydraulic jacks, commonly used in construction sites

Results (I)

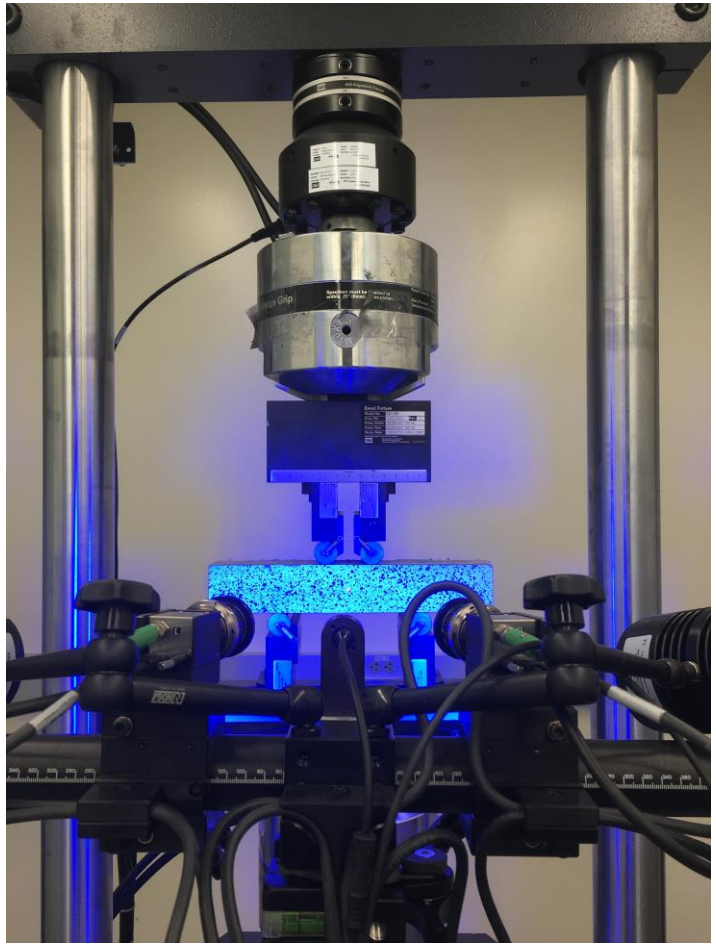
After curing for 28 days, strong UDC samples (2x6’) are produced

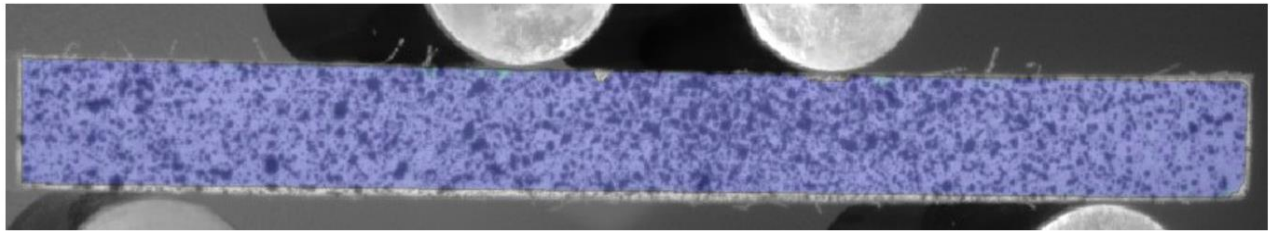
Results (I)

500-lb UDC Sample 3 (28-day)									
Compressive strength (psi)					Flexural strength (psi)				
Location		Ave.	Stdev.	Goal	Location		Ave.	Stdev.	Goal
Corner	top	15057.85	532.29	6500.00	Corner	top	2201.68	124.73	1200.00
	bottom	15169.52	337.94			bottom	2158.17	145.04	
Interior	top	15053.49	770.15		Interior	top	2130.61	142.14	
	bottom	14429.83	369.85			bottom	2298.85	123.28	
Boundary	top	14609.68	337.94		Boundary	top	2324.96	98.63	
	bottom	14605.33	684.58			bottom	2288.70	133.43	

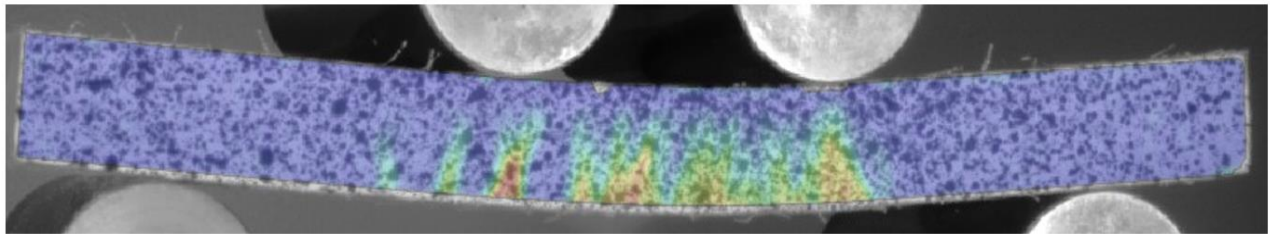
* 4 specimens were tested for each type of location;
* Reference concrete (no compaction, ~25% cement binder)
    - Compressive strength: 6915 psi
    - Flexural strength: 935 psi
* Toughness: more than 20x > reference concrete

Results (II) - UDC Ductility

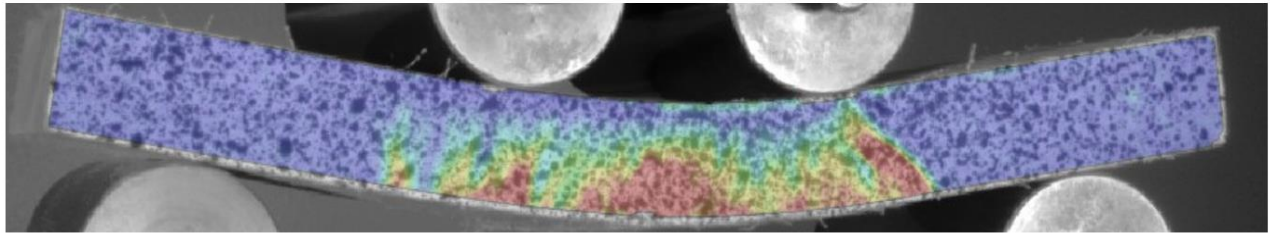




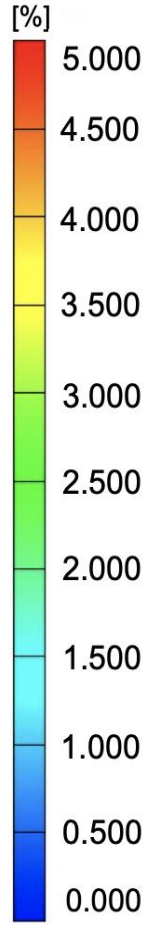
(i) displacement @ roller = 0 in.



(ii) displacement @ roller = 0.12 in.



(iii) displacement @ roller = 0.23 in.

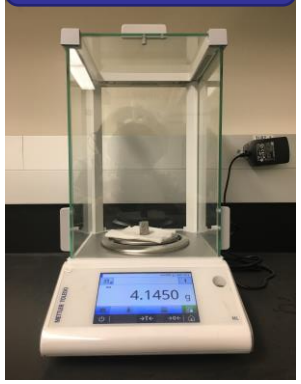


Results (II) – UDC Durability

1. Sample conditioning

2. Dried sample

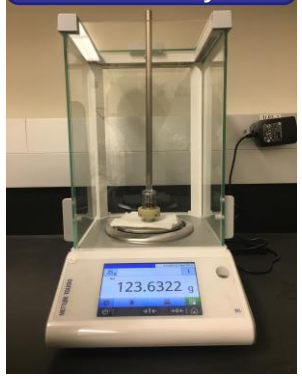
3. Weigh sample



4. Assemble penetrometer

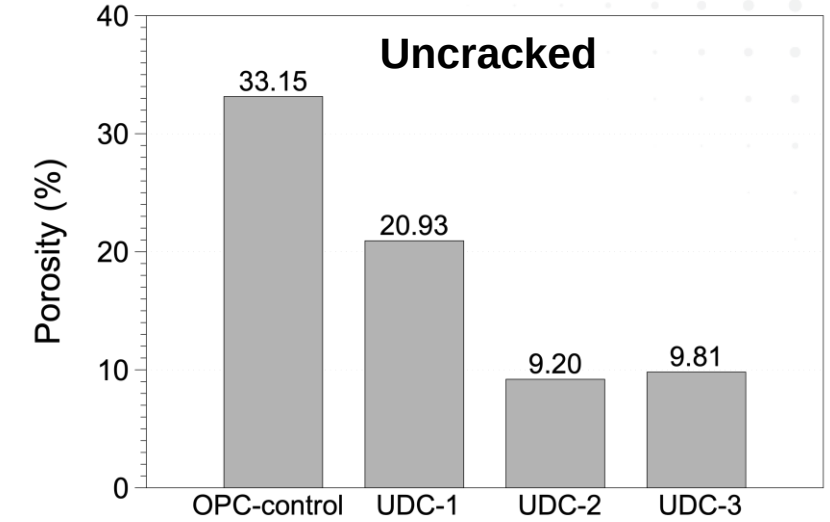
5. Low-pressure analysis

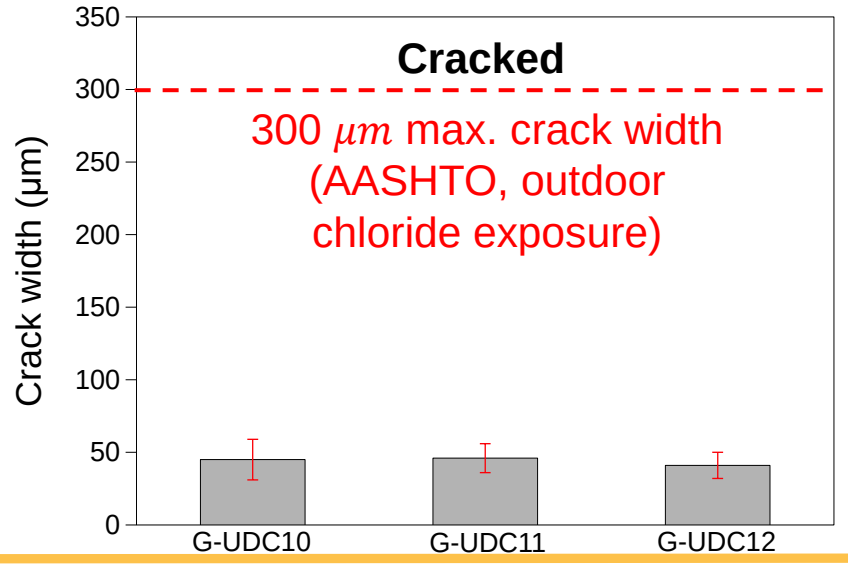
6. Weigh the assembly



7. High-pressure analysis

Mercury Intrusion Porosimetry





CHANGING WHAT'S POSSIBLE

Challenges and Risks

- In the past, the high cost limits the use of advanced concrete materials
- In our R&D, we aim to develop low-cost, high-performance concrete by
  - Greatly reducing the binder content
  - Simplifying the mixing/processing procedure

  The goal is to keep the total cost below $65/ton

- Main risk: scalability (fiber mixing, compaction) → Solved
- Main risk: The best market niche

Potential Partnerships

- We are seeking potential industrial and T2M partners
  - Licensing vs. start up

- To other teams: If you have a great binder, we may compact the material to
  - Densify the microstructure and greatly improve the strength/ductility, or
  - Largely reduce the binder content, with the strength unchanged

Summary Slide

- Ultralow-binder-content durable concrete (UDC)
  - Compaction: a very low binder content (10~15%) → simple premixing, low materials cost, green (low carbon emission), less demanding for class F fly ash (if geopolymer binder), highly densified microstructure, high strength, high ductility
  - Chemistry and micromechanics tailoring: ultrahigh ductility and durability
- Our team
  - Yu Qiao, UCSD (inventor of the compaction formation technique)
  - Mo Li, UCI (advanced binders, UDC ductility tailoring)
  - Yeshaya Koblick (T2M)
- Project goal
  - Prove the concept (500-lb samples)
  - Prove the cost efficiency (<$65/ton, including labor, equipment, waste)